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HYGROTHERMAL BEHAVIOUR OF A HEMP CONCRETE WALL: INFLUENCE OF SORPTION MODELLING

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KEYWORDS: *transient HAM model, hemp concrete, porous media, sorption*

SUMMARY:
Constructions built with environmentally friendly materials like hemp concrete know currently a real development. The development of numerical models able to evaluate their hygrothermal behaviour turns out to be a precious tool for their study. The model deals with coupled heat, mass and air transfer through multi-layer 1D porous media submitted to climatic variations. The model is used to simulate the behaviour of a hemp concrete wall. Comparison between simulation and experiment is done showing the importance of taking into account hysteresis for sorption isotherm modelling..

1. Introduction

In the context of sustainable development, one of the concerns in building construction is the choice of environmentally friendly materials. Indeed, it has some impacts on exhaustion of natural resources, energy consumption, polluting emission, etc....Hemp concrete (hemp and lime mortar) is a material more and more studied (Samri 2008, Evrard 2008). In order to predict the hygrothermal behaviour of this material, a collaborating project with industrial partner is lead and experimental tests and numerical studies are investigated. The main objective of this paper is to underline the difficulty to simulate the real thermohydric behaviour of hemp concrete under variable climatic conditions. So, a 1D numerical model is presented and experimental data recorded on a hemp concrete wall is described. Thus, numerical and experimental results are compared inducing a reflexion about on the real hygrothermal behaviour of hemp concrete.

2. Presentation of the model

2.1 Constitutive equations

Mass transfers are governed by humidity transport in liquid and vapour forms and by airflow through the structure. Vapour diffusion is given by Fick's law and liquid transport by Darcy's law.

$$\begin{gathered}\frac{dw}{d\varphi}\frac{\partial\varphi}{\partial t}=\frac{\partial}{\partial x}\left(\delta_p p_{sat}\frac{\partial\varphi}{\partial x}+\delta_p\varphi\frac{dp_{sat}}{dT}\frac{\partial T}{\partial x}\right)-\delta_a\frac{0.622}{p_{atm}}\frac{\Delta P}{e}\left(p_{sat}\frac{\partial\varphi}{\partial x}+\varphi\frac{dp_{sat}}{dT}\frac{\partial T}{\partial x}\right)\\+\frac{\partial}{\partial x}\left(K\rho_w R_{H_20}\frac{T}{\varphi}\cdot\frac{\partial\varphi}{\partial x}+K\rho_w R_{H_20}\ln(\varphi)\cdot\frac{\partial T}{\partial x}\right)\\\frac{\partial}{\partial x}\left(\delta_a\frac{\Delta P}{e}\right)=0\end{gathered}\qquad(1)$$

With φ the relative humidity, T the temperature, w the water content, δ_p the vapour permeability of moist material, ρ_a the air density, p_{sat} , p_{atm}, p_a the saturated vapour, atmospheric, partial air pressures, ρ_w the water density, K the liquid conductivity of the material, R_{H2O} the vapour perfect gas constant, δ_a air permeability of the material and $\Delta P/e$ the pressure gradient through the wall.

Heat transfer is carried out by conduction, convection due to the heat transport by air, liquid and vapour water and phase change in pores.

$$\begin{aligned}\rho_0 C^* \frac{\partial T}{\partial t} &= \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \left(C_{p_v} T + l_v\right) \frac{\partial}{\partial x}\left(\delta_p p_{sat} \frac{\partial \varphi}{\partial x} + \delta_p \varphi \frac{dp_{sat}}{dT} \frac{\partial T}{\partial x}\right) \\ &+ C_{p_l} T \frac{\partial}{\partial x}\left(K\rho_w R_{H_20} \frac{T}{\varphi} \cdot \frac{\partial \varphi}{\partial x} + K\rho_w R_{H_20} \ln(\varphi) \cdot \frac{\partial T}{\partial x}\right) + C_{p_a} T \frac{\partial}{\partial x}\left(2\delta_a \frac{\Delta P}{e}\right)\end{aligned} \tag{2}$$

With ρ_0 the density of the dry material, C_{pv}, C_{pl}, C_{pa} the specific heat capacity of vapour, liquid water and air, C^* the equivalent specific heat capacity of the moist material, λ the equivalent specific heat conductivity of the moist material, l_v the latent heat of evaporation.

2.2 Boundary conditions

Considering an air movement directed from inside to outside, the boundary conditions system is:

$$g_{ext} = \beta_{ext}\left(p_{ext} - p_{surf}\right) + \frac{0.622}{p_{atm}} \rho_a V \left(p_{ext} - p_{surf}\right) \qquad g_{\text{int}} = \beta_{\text{int}}\left(p_{\text{int}} - p_{surf}\right) \tag{3}$$

$$q_{ext} = h_{ext}\left(T_{ext} - T_{surf}\right) + \rho_a C_a V \left(T_{ext} - T_{surf}\right) + l_v g_{ext} \qquad q_{\text{int}} = h_{\text{int}}\left(T_{\text{int}} - T_{surf}\right) + l_v g_{\text{int}} \tag{4}$$

with h and β the heat and mass surface coefficients and V the airflow velocity.

2.3 Validation

The governing system of equation is implemented in COMSOL Multiphysics software, a finite-element solver particularly suited to strongly-coupled transient equations systems in multilayer or multidimensional configurations met in buildings envelope (Tariku 2008, Schijndel 2008).

The present model is benchmarked against the European Norm NF EN 15026 (2008) and the international benchmark HAMSTAD WP2 (Hagentoft 2004). The five exercises of this benchmark are suited to assess the performance and accuracy of hygrothermal model in one dimensional configuration. These exercises are dealing with simultaneous heat and mass moisture transfer through single or multi layers wall combined with for example airflow through the wall or rain at the surface. The different cases allow checking the capacity of the model to describe heat and moisture transfer in various situations. The complete results obtained with the present modelling are presented in Ait Oumeziane (2011). The good agreement of our model with all the test cases enables to plan a confrontation with an experimental application dealing with hemp concrete behaviour.

3. Material data and experimental setup

3.1 Hemp concrete properties

Properties of hemp concrete are obtained from a set of experiments performed in our laboratory and presented in Chamoin (2008) and Collet (2008). For this study the influence of the water content on conductivity and permeability is neglected. The following values are used: the density of the dry material ρ_0 = 390 kg.m^{-3}, the heat conductivity λ = 0.11 W.m^{-1}.K^{-1}, the specific heat capacity C_0 = 1000 J.kg^{-1} and the vapour permeability δ_p = 2.5.10^{-11} kg.m^{-1}.s^{-1}.Pa^{-1}.

The sorption characteristics are given by the discrete values obtained from experiment (water content at relative humidity of 11%, 23%, 33%, 43%, 58%, 81%, 90%, 95% and 97%).

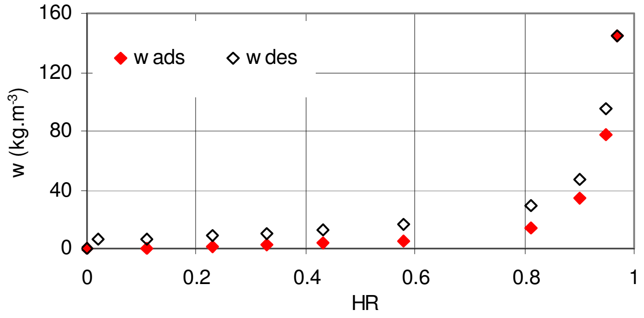


FIG 1 : Adsorption and desorption isotherms of hemp concrete

As already observed (Samri 2008) hemp concrete presents a hysteresis between main adsorption and main desorption (figure 1). For the simulation, either the main adsorption or the main desorption characteristics can be used. The modelling of the sorption isotherm curves on the entire relative humidity range is ensured using COMSOL interpolation with piecewise cubic functions.

3.2 Description of the hemp concrete wall

Two climatic rooms are separated by a mixed wall built with 31 blocks of hemp concrete and wood elements. These rooms simulate interior and exterior climate (figure 2). Blocks are cast from moulds which are 60 cm long, 30 cm wide and 30 cm high. Furthermore, in these parallelepipeds, two rectangular holes are intended for wood posts ensuring wall consolidation and four circular holes allowing in-house networks installation. A mortar composed of lime, water and hemp ensures the assembly and the filling of unused gaps. The wall is representative of wall of a real hemp building.

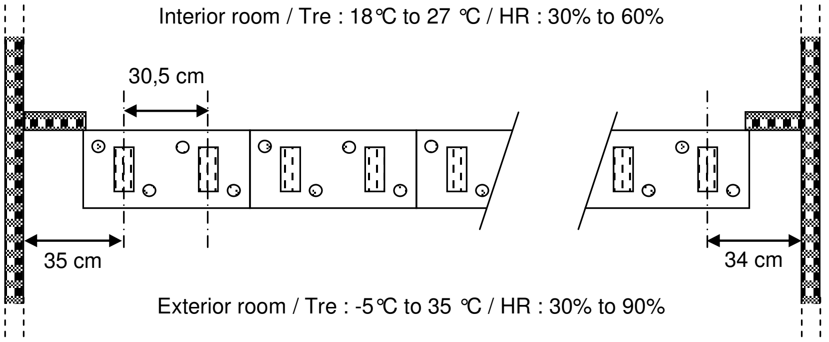


FIG 2 : Wall configuration and hemp concrete block picture

3.3 Metrology placed in the wall

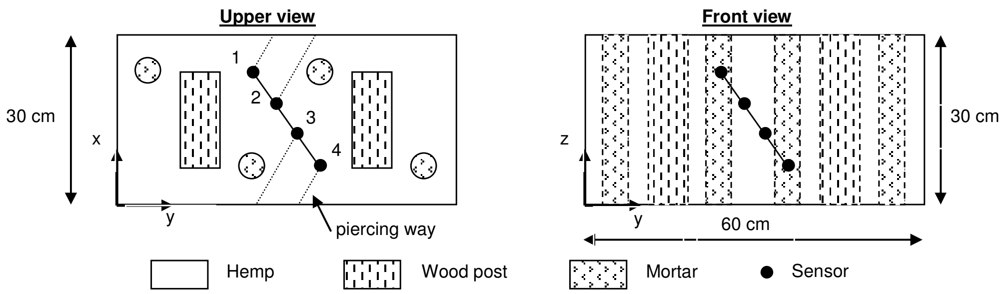
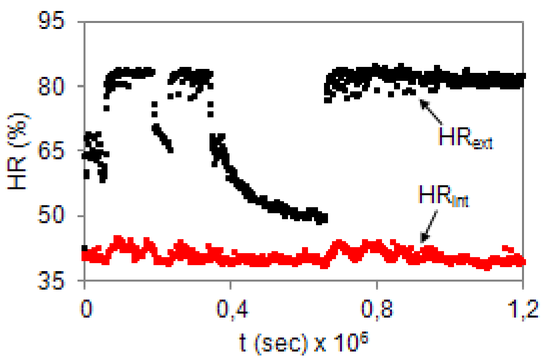


FIG 3 : hemp concrete block (x_1 = 0.08 m, x_2 = 0.12 m, x_3 = 0.18 m and x_4 = 0.22 m)

In order to describe temperature and relative humidity variations, several humidity sensors and thermocouples have been put inside the wall, at wall surfaces and in both surroundings. The created gaps for sensors putting in are chosen in order to limit the effect on one dimensional mass and heat transfer (figure 3). The acquisition system collects the measures every 5 minutes. In this paper, only four humidity sensors and four thermocouples for blocks in the middle of the wall are studied.

3.4 Climatic solicitation

Before the beginning of the test, the wall is stabilized at 40 % and 23°C by keeping constant exterior and interior surroundings at 40 % and 23°C. The test duration is about 2 weeks. In the studied case the temperature is set to 23°C for both sides of the wall, the interior relative humidity is set to 40% and the exterior relative humidity varies between 50% and 80%. The measured external and internal temperatures and relative humidity are presented in figure 4.



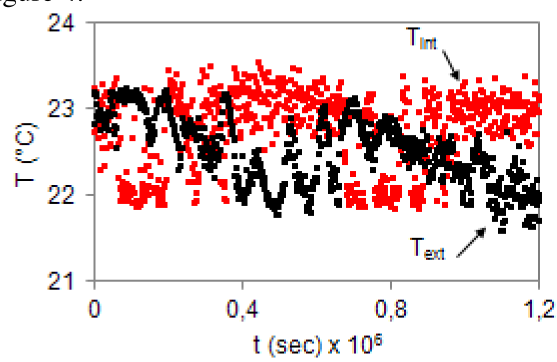


FIG 4 : Recording of exterior and interior relative humidity and temperature

4. Simulation of the behaviour of hemp concrete wall

In this section, the model results are confronted to the experimental data obtained on the hemp concrete wall submitted to the previously presented climatic solicitation. In this case, no air transfer is present since the wall is not submitted to an overall pressure gradient. Considering the range of relative humidity, namely between 40% and 80%, the liquid water flux is negligible. Although the presence of wood and gaps in the wall induces a three dimensional transfer problem, the simulation is carried out in one dimension. This simplification is a tough one: if the wood posts can reasonably be supposed not disturbing the transfers through the particular block studied, the presence of network gap filled with lime mortar is certainly of importance. However this effect has been limited as much as possible since gaps are filled with hemp mortar.

4.1 Simulation parameters

The simulation lasts 2 weeks and the time step is 5minutes. The initial temperature is taken at 23°C and the initial relative humidity at 41.5%. The heat transfer surface coefficient is taken to 5 $W.m^{-2}.K^{-1}$ for each side of the wall. The mass surface coefficient is determined with the Lewis relation resulting in values around 5.10^{-8} $s.m^{-1}$ for both sides of the wall.

4.2 Results analysis

Figure 5 presents the distribution of relative humidity and temperature (only two depths to ensure temperature graph readability) in case of calculus assuming that the sorption isotherm follows the adsorption curve. A good agreement between simulation results and experiment is achieved for the temperatures. However, the simulated relative humidity variations are far from the experimental ones.

The simulated relative humidity remains underestimated during the whole test. This kind of trends when dealing with hemp concrete wall simulation as already been reported by Samri (2008).

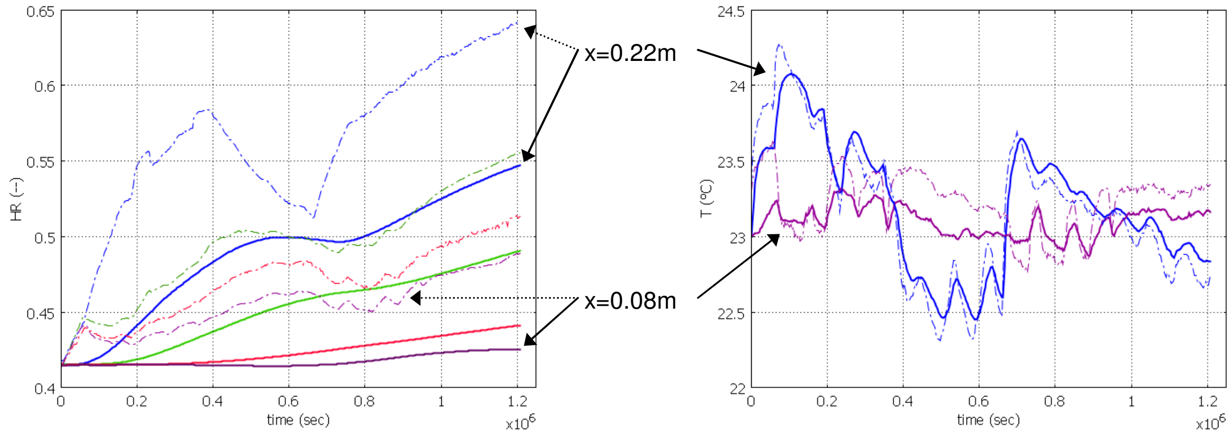


FIG 5 : Experimental (dashed lines) and simulated (continuous lines) relative humidity (left) and temperature (right) with adsorption isotherm for different depths (x = 0.22 m, 0.18 m, 0.12 m, 0.08m).

4.3 Sensitivity of parameters

To identify the influent parameters a sensitivity study is done. First the influence of material property is tested by applying 10% variation to heat capacity, heat conductivity and vapour permeability. None of these parameters shows a significant impact on the relative humidity and temperature evolutions. Influence of the modelling of the sorption isotherm is evaluated by using desorption curve or changing the hydric storage capacity. These hydric properties appear to be predominant. Influence of the modelling choice for the sorption isotherm is further studied in the next section.

5. Influence of sorption modelling

The adsorption/desorption isotherms used act as boundary curves which do not describe the real evolution of water content in current use. Due to hysteresis effect, water content for a given relative humidity is between the values given by adsorption and desorption curves depending on the previous solicitations of the material. The water content is not only under or overestimated according to the choice of adsorption or desorption curve but above all its storage capacity is in each case widely overestimated. In order to improve the modelling the influence of intermediary adsorption curves is investigated. For commodity of representation, only the results at the position x = 0.22 m are presented in the following sections.

5.1 First proposition for intermediate sorption curves.

Before the beginning of the present experiment, the wall has been subjected to different cycles of sorption/desorption during its life. So it is justified to admit that the initial water content at time zero is between the values given by the boundary adsorption and desorption curves. Let us suppose that this initial water content is the one given by the desorption curve at the ambient relative humidity of 40% (the stabilized humidity at the beginning of the experiment). From this state, the hydric capacity will be necessarily lower than the one given by the adsorption curve. Physically this conclusion is based on the fact that at a given relative humidity (here 40%), more pores are load of water when water content is closer to the desorption curve than to the adsorption one, thus reducing the storage capacity. This leads to the fact that the possible intermediate sorption isotherms need to have a slope lower than the slope of the adsorption curve. Since the original sorption curves are defined with discrete values obtained from experiment (water content at relative humidity of 11%, 23%, 33%, 43%, 58%, 81%, 90%, 95% and 97%), the intermediate sorption curves will be defined also with discrete values at the same relative humidity. Since the range of humidity is from 40% to 80% in this case water content at 43%, 58% and 81% have to be defined for the intermediate sorption curves. For the simulation COMSOL interpolation with piecewise cubic functions between these discrete values is still used.

The first point of the intermediate sorption curves is chosen as $w_{des}(0.43)$ because it is an experimental discrete point of the desorption curve very close to the supposed initial value $w_{des}(0.40)$. Boudary adsorption curve, boundary desorption curve and $w_{des}(0.43)$ stand for limits for the real water content during the experiment. So the second and third point of the intermediate sorption curves, respectively $w_{inter}(0.58)$ and $w_{inter}(0.81)$, are defined as fractions of the difference between the extreme limits given before :

$$\begin{aligned} w_{\text{inter}}(0.58) &= w_{des}(0.43) + \alpha\big(w_{des}(0.58) - w_{des}(0.43)\big) \\ w_{\text{inter}}(0.81) &= w_{ads}(0.81) + \alpha\big(w_{des}(0.81) - w_{ads}(0.81)\big) \end{aligned} \tag{5}$$

α is a fraction defined between 0 and 1. In order to show the influence of the intermediary sorption curve defined, the values of α are taken to 2/3, 1/3, 1/5 and 1/10. The different points used are presented on figure 6. Figure 7 presents the variations of relative humidity in these cases.

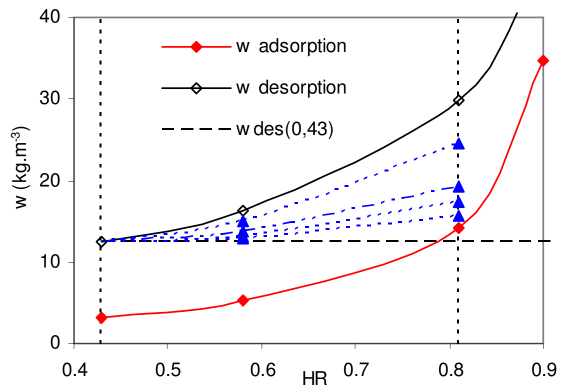


FIG 6 : Intermediate sorption curves for initial water content of w = $w_{des}(0.43)$

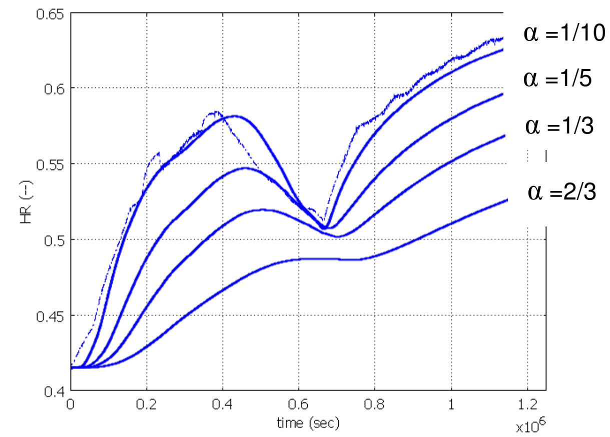


FIG 7 : Distributions of relative humidity at the depth x = 0.22 m for different values of α (dashed line for experiment)

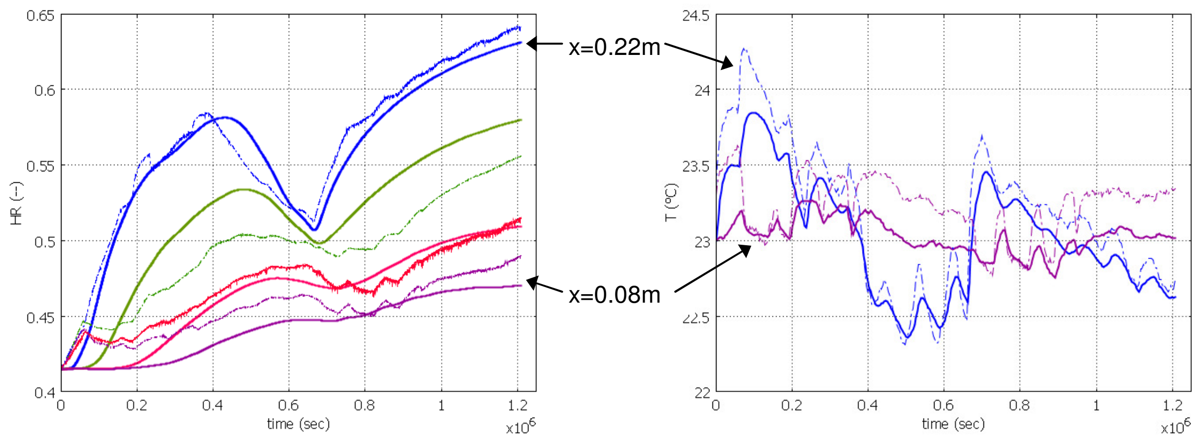


FIG 8 : Experimental (dashed lines) and simulated (continuous lines) relative humidity (left) and temperature (right) for α =1/10 from an initial water on the desorption curve for different depths (x = 0.22 m, 0.18 m, 0.12 m, 0.08m).

The results show that the lower the α values are, the better the fit with experiment is achieved with an optimum result got for α =1/10. For this value of α =1/10, complete results for temperature (only two depths to ensure temperature graph readability) and relative humidity at different deeps are presented in figure 8. The reduction of the slope of the sorption curve seems therefore to be the sensitive parameter.

5.2 Evolution of the first proposition for intermediate sorption curves

In the preceding section the initial water content was supposed equal to the higher possible one at the prescribed relative humidity: $w_{des}(0.43)$. However this initial value is reasonably comprised between $w_{des}(0.43)$ and $w_{ads}(0.43)$. In this part the influence of that choice is evaluated by taking an initial water content between $w_{des}(0.43)$ and $w_{ads}(0.43)$. The three points used to build the curves are $w_{average}(0.43)$, $w_{inter}(0.58)$ and $w_{inter}(0.81)$ with:

$$\begin{aligned} w_{average}(0.43) &= \left(w_{ads}(0.43) + w_{dés}(0.43)\right)/2 \\ w_{\text{inter}}(0.58) &= w_{moy}(0.43) + \alpha\left(w_{des}(0.58) - w_{moy}(0.43)\right) \\ w_{\text{inter}}(0.81) &= w_{ads}(0.81) + \alpha\left(w_{des}(0.81) - w_{ads}(0.81)\right) \end{aligned} \tag{6}$$

Figure 9 shows the different points got with an initial water content taken in the middle of the adsorption and the desorption curves and some values of α still equal to 2/3, 1/3, 1/5 and 1/10. The same trends are observed: the lower the slope is, the better is the fit with experiment. Figure 10 compares the results for relative humidity for α =1/10 and for the different initial water content: $w_{des}(0.43)$ and $w_{average}(0.43)$.

A significant difference between the two simulations is observed which is partly due to the higher mean slope of the intermediate sorption curve in the last case. These tests confirm that the model of intermediary curves is a determinant parameter to simulate the hemp concrete wall behaviour.

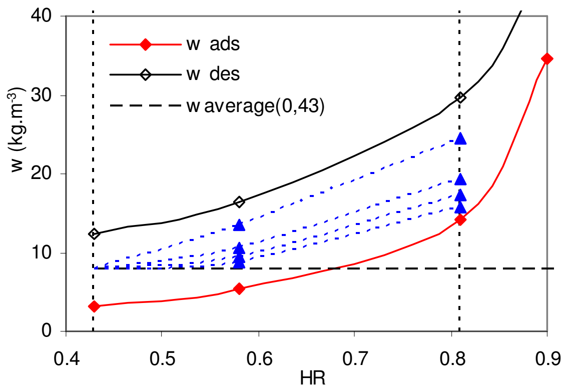


FIG 9 : Intermediate sorption curves for initial water content of w = $w_{average}(0.43)$

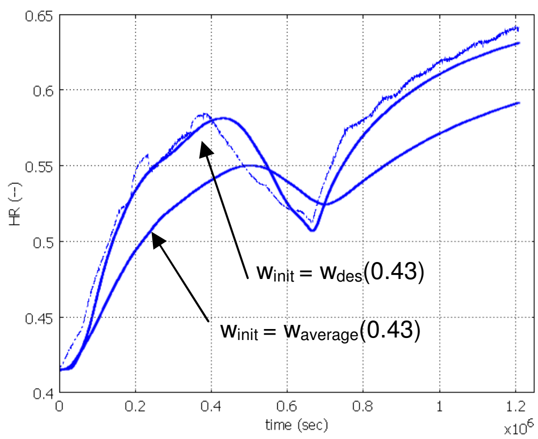


FIG 10 : Distribution of relative humidity at the depth x = 0.22 m for α = 1/10 from different initial water contents (dashed line for experiment)

6. Conclusion

This paper provides various indications regarding the real hygrothermal behaviour of hemp concrete. For this material, a single isotherm sorption curve is not convenient. Taking account the hysteresis of the sorption isotherms seems to be a determinant factor for the modelling of mass transfer : it is essential to model correctly the storage capacity and initial water content.

The proposed discussion about intermediate curves gives interesting way to model the phenomena with a good accuracy. But physical explanations are still expected. Comparison with some models of hysteresis like Pedersen (1990) or Mualem (2009) must be studied. Moreover, the hemp concrete wall is a composite wall (presence of wood, circular holes filled with mortar) so a 2D study is needed.

7. Acknowledgements

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References

Ait Oumeziane Y. Bart M. Moissette S. Lanos C. 2011. Modélisation du transfert d'air, de masse et de chaleur aux travers de parois multicouches. X$^{\text{ème}}$ Colloque Interuniversitaire Franco-Québécois. Saguenay. Canada

Carmeliet J. De Wit M. Janssen H. 2005. Hysteresis and moisture buffering of wood. Seventh Nordic Symposium on building physics. Reykjavik. Island

Chamoin J. 2008. Optimisation de béton de chanvre projeté et moulé – caractérisation du matériau de référence. 26$^{\text{èmes}}$ rencontres de l'Association Universitaire de Génie Civil. Nancy. France.

Collet F. Bart M. Serres L. Miriel J. 2008. Porous structure and water vapour sorption of hemp-based materials. Construction and Building Materials. 22. p. 1271-1280.

Evrard A. 2008. Transient hygrothermal behaviour of Lime-Hemp Materials. PhD-Thesis. Université Catholique de Louvain. Belgium.

Hagentoft C.E, Kalagasidis A.S, Adl-Zarrabi B, Roels S, Carmeliet J, Hens H, Grunewald J, Kunk M, Becker R, Shamir D, Adan O, Brocken H, Kumaran K, Djebbar R. 2004. Assessment Method for Numerical Prediction Models for Combined Heat, Air and Moisture Transfer in Building Components: Benchmarks for One-dimensional Cases. Journal of Thermal Envelope and Building Science 27(4). p. 327-352.

Kunzel H. M. 1995. Simultaneous heat and moisture transport in building components. Fraunhofer IRB Verlag Stuttgart. Germany

Mualem Y, Beriozkin A. 2009. General scaling rules of the hysteretic water retention function based on Mualem's domain theory. European Journal of SOIL Science. n°60. p 652-661.

NF EN 15026. 2008. Evaluation du transfert d'humidité par simulation numérique. Performance hygrothermique des composants et des parois de bâtiments. *AFNOR*.

Pedersen C.R. 1990. Combined heat and moisture transfer in building constructions. PhD Thesis. Technical University of Denmark. Denmark

Samri D. 2008. Analyse physique et caractérisation hygrothermique des matériaux de construction: approche expérimentale et modélisation numérique. PhD-Thesis. Institut National Sciences Appliquées de Lyon. France.

Schijndel A.W.M. 2008. Heat and moisture modeling benchmarks using COMSOL. Proceedings of the COMSOL conference. Hannover. Germany

Tariku F. Kumaran K. Fazio P. 2008. Development and benchmarking of a new hygrothermal model. 11$^{\text{th}}$ International Conference on Durability of Building Materials and Components. Istanbul. Turkey.